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Morphological Processing Before and During Children's Spelling

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ABSTRACT

Our understanding of spelling development has largely been gleaned from analysis of children's accuracy at spelling words under varying conditions and the nature of their errors. Here, we consider whether handwriting durations can inform us about the time course with which children use morphological information to produce accurate spellings of root morphemes. Six- to 7-year-old (n = 23) and 8- to 11-year-old (n = 25) children produced 28 target spellings in a spelling-to-dictation task. Target words were matched quadruplets of base, control, inflected, and derived words beginning with the same letters (e.g., *rock, rocket, rocking, rocky*). Both groups of children showed evidence of morphological processing as they prepared their spelling; writing onset latencies were shorter for two-morpheme words than control words. The findings are consistent with statistical learning theories of spelling development and theories of lexical quality that include a role of morphology.

Spelling has long been considered a window into how children think about words (e.g., Morris & Perney, 1984; Ouellette & Sénéchal, 2008; Treiman, 1998). We have learned a great deal through naturalistic and experimental research examining both children's spelling accuracy and their errors. For instance, children are more likely to include the penultimate /n/ in spelling two-morpheme words such as *pinned* than in one-morpheme words such as *wind*, suggesting a reliance on morphemes, the smallest units of meaning in language, in spelling (e.g., Treiman & Cassar, 1996; Treiman, Cassar, & Zukowski, 1994). We extend this evidence to explore the mechanisms underlying morphological processing during spelling. We build on recent adult research (Quémart & Lambert, 2017) to establish the utility of children's handwriting durations as offering insight into the time course of the processes children use before and during spelling of two-morpheme words.

Changes with age in children's processing during spelling: studies of spelling production

Behavioural studies show that children use morphemes in their spelling from an early age. Most evidence comes from the product of spelling processes, particularly spelling accuracy. For instance, Deacon and colleagues showed that children as young as 6 are more likely to spell whole root words correctly in inflected and derived words than in one-morpheme comparison words. Children are more likely to spell *rock* correctly in its two-morpheme relatives *rocking* and *rocky* than in the single-morpheme word *rocket* (Deacon, 2008; Deacon & Bryant, 2006a, 2006b). Similar evidence comes from effects of morphology on children's spellings of single letters. For instance, 5-year-olds are more likely to spell the alveolar flap correctly as *t* when it is part of a root (e.g., *dirty*) than when it is not (e.g., *city*; Treiman et al., 1994; see also Treiman & Cassar, 1996).

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The size of these effects appears to increase with age, suggesting that morphological processing in spelling continues to develop through the early elementary years. The influence of root morphemes on spelling accuracy appears maximal by 9 years of age, both for whole roots and target letters (Deacon & Dhooge, 2010; Treiman et al., 1994). High spelling accuracy in the upper elementary school years makes the detection of underlying processes challenging, particularly with regards to whether use of morphemes during spelling changes as children age. At 9 years, accuracy rates were generally at 85% and above (Deacon & Dhooge, 2010; Treiman et al., 1994). Certainly, we expect that morphological processing continues to occur during spelling beyond this age (see, e.g., Carlisle, 1988). However, once near-ceiling accuracy is achieved, morphological processing cannot be detected on the basis of quantitative analysis of accuracy rates or qualitative analyses of spelling errors. Yet we need to examine the processes involved during the production of correct spellings to determine if morphological processing during spelling results in accurate spellings.

In the present study, we use spatiotemporal handwriting analysis to examine the timing of processes during spelling production. This approach enables us to address a new question—whether and when morphological processing occurs during correct spelling. We do so with children of varying ages to address the question of potential developmental change.

Questions of change across spelling development speak directly to theories of spelling development. Theories of spelling development have long focused on the question of the age at which children rely on morphemes. Classic "late" theories argue that young children's reading and spelling is initially dominated by phonology, with a later transition to attention to morphological features at around 8 years of age (e.g., Ehri, 1995, 2005; Gentry, 1982). "Early" theories put forward the view that even young children's spellings are influenced by multiple features, including morphology, likely as a result of a statistical learning mechanism (e.g., Deacon, Conrad, & Pacton, 2008; Treiman, 2017). Exploring the trajectory of children's morphological processing in spelling by examining younger (i.e., 6 and 7 years) and older children (i.e., 8–11 years) is key in distinguishing these approaches. Adding investigation of morphemic effects on the time course of children's spelling is a novel means to investigate developmental changes.

Time course of morphological processing during children's spelling

Another unresolved issue lies in when children draw upon morphological information during the spelling process itself. Theories of spelling development have been largely agnostic on this question, focusing instead when in development, not when in processing. Yet it is an intriguing question; it gets closer to just how children process morphology. Here we turn to models of adult spelling for ideas on how this might occur.

Theories of skilled spelling highlight three stages of the spelling process—input identification, central orthographic processes, and peripheral orthographic processes (e.g., Bonin, Méot, Lagarrigue, & Roux, 2015; Olive, 2014). These processes are hierarchically organised, with higher level conceptual processes operating on larger units (Van Galen, 1991). Input identification processes are domain-specific processes triggered by the prompt to spell; they continue through to lexical activation within the semantic system. In spelling-to-dictation, input identification includes auditory analysis and spoken word identification. Central orthographic processes are the linguistic processes used to formulate the graphemic representation of the spelling. The central orthographic processes take writers from the emergence of the concept of the word within the semantic system to holding the graphemic representations in working memory. These graphemic (letter-based) representations might be whole word units, or sublexical units such as morphemes. Peripheral orthographic processes come online for spellings to be produced; these are sensorimotor processes that convert graphemic representations into the fine finger movements necessary to produce the written word. In terms of our specific question, morphological processing might occur during central orthographic processes because these begin in the semantic system. This idea is consistent with multiple theories of lexical representations that point to the role of morphemes in consolidation in lexical memory;

morphemes expedite access to lexical representations (Harm & Seidenberg, 2004; Nation, 2009; Perfetti, 2007) through the use of multiple codes or routes through the orthographic system (Grainger, Lété, Bertand, Dufau, & Ziegler, 2012; Grainger & Ziegler, 2011).

A small set of studies have begun to test predictions about the time course of morphological processing during spelling. The majority of the studies of morphological processing before or during handwriting have been conducted with adults and involve copying, rather than spelling (Kandel, Álvarez, & Vallée, 2008; Kandel, Spinelli, Tremblay, Guerassimovitch, & Álvarez, 2012; Quémart & Lambert, 2018). Studies of French adults by Kandel and colleagues (Kandel et al., 2008; see also 2012) demonstrate evidence of morphological processing in handwriting durations both before and during copying. In Kandel et al.'s (2008) pioneering study, adults took longer to begin to copy derived words than pseudosuffixed words; this points to evidence of morphological processing before initiating copying. Kandel and colleagues (Kandel et al., 2008; Kandel et al., 2012) found that handwriting durations were longer in both letter stroke durations and interletter intervals at the morpheme boundaries of derived words (e.g., *[prun][**eau**]*) compared to matched single morpheme pseudosuffixed words (e.g., *[pinc**eau**]*). Together this evidence points to morphological processing influencing the dynamics of adult handwriting production both before and during copying. This implicates a role for morphology in central orthographic processes.

Quémart and Lambert (2018) extended this line of work to examine morphological processing in children and adults, also using a copying task. For French-speaking adults, the time prior to writing was shorter for derived words (e.g., *[fer**m**][**i**er]*) than matched single-morpheme control words (e.g., *[che**mi**se]*); these effects of morphological processing before copying did not emerge for 10- or 12-year-old children. Adults and 12-year-old children also showed effects of morphological processing during copying; letter writing durations were longer when a letter immediately preceded a morpheme boundary in derived words (i.e., the final letter of the root morpheme) than when it was in the same location in single-morpheme control words. Ten-year-old children did not show such effects. These findings suggest a developmental progression. Adults showed evidence of morphological processing before and during copying; 12-year-old children showed effects of morphological processing during copying, and 10-year-olds did not show either effects.

All studies of handwriting durations reviewed to this point used copying, rather than spelling tasks. Although we would expect some of the underlying processes to overlap, there are important differences in the nature of these tasks. In principle, copying can be achieved without lexical access, by transcribing letter by letter. In reality, lexical access is often so automatic that this is unlikely, certainly for skilled readers (e.g., Lambert, Alamargot, Larocque, & Caporossi, 2011). Even so, copying through lexical access involves visual word recognition during input identification. As a result, the effects of morphological structure in copying could be due to processes involved in either reading or spelling, or a potentially cognitively demanding interaction between these processes. Spelling to dictation, on the other hand, does not involve visual word recognition. Instead, input identification processes require auditory analysis and spoken word recognition (Bonin et al., 2015). Because most behavioural research uses traditional spelling-to-dictation tasks, the use of parallel tasks would align new knowledge gathered on handwriting durations with existing data and theory.

Building on the earlier studies with copying tasks, Quémart and Lambert (2017) pioneered the examination of effects of morphological processing on handwriting durations in spelling tasks—using the classic dictation task. In this study, French adults showed effects of morphological processing during, but not before, spelling. During spelling, interletter latency was longer at morpheme boundaries (e.g., *[v**o.l**][eur]*) of derived words compared to the same letters (e.g., *ol*) in single morpheme control words (e.g., *[s**o.l**eil]*). These results suggest that morphological processing is an element of central orthographic processes rather than input identification. This contrasts with prior studies of copying, where morphological processing seemed to occur at both levels, at least for skilled adults (Kandel et al., 2008; Kandel et al., 2012; Quémart & Lambert, 2018).

Research to date suggests that morphological processing influences input identification and central orthographic processes. However, little is known about morphological processing before and during spelling for children. It is intriguing that the only study to examine 10-year-old children's copying found little evidence of morphological processing in time course measures (Quémart & Lambert, 2018). This contrasts sharply with evidence for morphological processing at much younger ages from the many studies of children's spelling accuracy (e.g., Breadmore & Carroll, 2016; Deacon, 2008; Treiman & Cassar, 1996). Here, we bridge this empirical gap to inform theoretical debate about morphological processing in children's spelling.

Our research objective is to evaluate morphological processing before and during children's spelling. To do so, we used a spelling-to-dictation paradigm from a behavioural study (Deacon & Dhooge, 2010), adapting it for use with handwriting recorded on a graphics tablet. This enabled us to align new evidence from handwriting durations with existing developmental evidence and theory. Deacon and Dhooge (2010) contrasted 7- to 10-year-old children's spelling of root morphemes (e.g., *rock*) to the spelling of the same letters embedded within longer words that were inflected, derived, and unrelated control words (e.g., *rocks, rocky, rocket*, respectively). As much as possible, pronunciation was also consistent for these letters. In Deacon and Dhooge's study, children applied the principle of root consistency to the same extent with inflected and derived words, with increasing use of this principle with age. By recording handwriting durations in the same task, we examine whether evidence of morphological processing before and during writing can be observed in children's spelling to dictation. Writing onset latencies enable us to explore processes that occur before writing begins; we measured this as the time from the prompt to spell until the pen touches the paper. Root writing times enable us to explore the impact of morphological structure during writing; we measured this as the time from when the pen touched the paper to begin writing until the pen was lifted at the boundary with the next morpheme. At this point the letters diverge between conditions and we cannot compare writing times.. Prior studies have found effects of morphological processing during writing at various points: before, at, and after the morpheme boundary (Kandel et al., 2012; Quémart & Lambert, 2017, 2018). However, beccause only the letters in the root overlapped in our stimuli, we could not examine writing times after this point. We evaluate whether these effects are different for younger versus older spellers and across inflected and derived words.

If morphological processing occurs before spelling, children would likely begin to write two-morpheme words more quickly than words of the same length that contain a single morpheme. Such findings would support the importance of morphological processing in input identification and central orthographic processes, as well as aligning with theories pointing to the role of morphemes in spelling due to the convergence of multiple codes (Grainger & Ziegler, 2011; Harm & Seidenberg, 2004; Treiman, 2017) and/or better quality lexical representations (Perfetti, 2007). If this is the case, we would expect faster writing onset latencies for two-morpheme words than single-morpheme comparison words of the same length, but no differences in durations during writing the letters in the root.

Such theories do not rule out the possibility that morphological processing occurs both before and during children's spelling. Processes may cascade through production to impact on timing. For example, morphological processing before spelling might enable children to begin to write two-morpheme words such as *tricked* having only prepared the first morpheme of *trick*. In contrast, children would have to prepare the whole word, such as *trickle*, for single-morpheme words. Differences in writing onset latencies could reflect preparation of fewer letters for two-morpheme words (whether inflected or derived) than control single-morpheme words. In this case, one would expect additional effects of continued morphological processing during spelling production—effects associated with preparation of the second morpheme if this is produced in serial. Specifically, we would expect children to slow down while spelling the roots of two-morpheme words compared to single-morpheme control words, to enable preparation of the suffix while writing the initial portion of the word. This would result in longer times to write the root for two-morpheme words (*tricked*) compared to single-morpheme control words of the same length (*trickle*). As such, effects on root writing times can help us to uncover processing of the morphological structure of words during spelling.

Given the limited available research base, it is difficult to predict precisely how such effects might differ with development. Classic theories (e.g., Ehri, 1995, 2005; Gentry, 1982) would suggest that effects of morphemes on children's spelling should emerge only for older children. Statistical learning theories would predict that both older and younger children would show effects of morphological processing (e.g., Deacon et al., 2008; Pacton & Deacon, 2008; Treiman, 2017). To evaluate these possibilities, we compared a group of younger (6- and 7-year-old) children with a group of older (8- to 11-year-old) children. According to classic phase theories (e.g., Ehri, 1995), children use primarily phonological strategies to spelling early in spelling development, with a transition at around age 8.

Method

Participants

Forty-eight participants 5;11 to 11;6 years of age were recruited from two sources. Thirty-eight took part during a free family science event in the Midlands, United Kingdom. Families took part in a range of science activities and received a certificate and a book. Forty-seven participants took part during this event, but nine were excluded from analyses due to having either special educational needs or incomplete data. A further 10 participants were recruited from a primary school through opt-in consent. A book was donated to the school library for each child who took part. All participants spoke English as their first language. None of the children included in the final sample were reported as having hearing, language, literacy, or special educational needs.

Word and nonword reading was assessed with the Test of Word Reading Efficiency (Rashotte, Torgesen, & Wagner, 1999) in accordance with the instruction manual. to confirm that all children were reading age appropriately. All children had a standard score greater than 90 on both sight word and phonemic decoding subtests, and average scores on the Test of Word Reading Efficiency show that children were above their chronological age in their reading ability. For analytic purposes, participants were grouped into two age groups: 23 younger children 5;11–7;11 years of age (nine male, 14 female) and 25 older children 8;0–11;6 years of age (14 male, 11 female). We describe these groups in the Results section as younger and older children. Further description of the background characteristics of these children is provided in Table 1.

Morphological spelling to dictation

The morphological spelling task was adapted from Deacon and Dhooge (2010). Small changes were made to sentence contexts to position the target word in sentence final position. One set of items (*fur–furs–furry–furnace*) was removed for administration with children with British rather than North American English dialect, due to rhoticity effecting the phonological overlap between items and concerns about whether the words would be in their vocabulary.

Table 1. Descriptive Background Statistics for Younger and Older Age Groups

	Younger	Older
	M (SD, Range)	M (SD, Range)
n	23	25
Age (years; months)	7;1 (0;7, 5;11–7;11)	9;2 (1;0, 8;0–11;6)
TOWRE sight word efficiency (standard score)	120.00 (10.30, 99–139)	111.56 (12.22, 91–133)
TOWRE phonemic decoding (standard score)	120.22 (12.91, 93–145)	114.08 (13.9, 95–141)

Note. TOWRE = Test of Word Reading Efficiency.

Design and stimuli

There were 28 target words, seven presented in base form as well as embedded within control, inflected, and derived words. Words in control, inflected, and derived conditions were matched for word length, suffix and sentence length, and frequency (as in Deacon & Dhooge, 2010). We confirmed this original matching using UK frequency norms from SUBTLEX-UK (Van Heuven, Mandera, Keuleers, & Brysbaert, 2014). Base words are necessarily both shorter and of higher frequency than all other word types. Key comparisons are made between control, inflected, and derived words. Here, initial sequences are perfectly matched for letter features, length, and frequency; they contain the same initial letters. Table 2 contains descriptive statistics, and the appendix contains a complete list of stimuli. Participants produced spellings for two practice items followed by all 28 experimental items.

Procedure

Stimulus presentation, recording and analysis of responses was controlled using Eye and Pen 2™ (Alamargot, Chesnet, Dansac, & Ros, 2006) running on a Toshiba Satellite Pro L850-1DV. Each item was audio-recorded by a female native British English speaker in the format "[Target]. Sentence ending in [Target]. [Target]." Both experimenter and participant listened using closed-cup headphones (Sennheiser HD215) at a volume that was comfortable for the child. The order within the trial procedure was as follows: auditory signal, 200 ms silence, audio-recorded spelling-to-dictation item, 50-ms silence, auditory cue to begin writing.

Participants used a Wacom Intuos Inking Pen to produce spellings on a sheet of A4 paper overlaid on a Wacom Intuos$_4$ PTK-1240 tablet to digitise their response. Before the experiment, children were given the following instructions: Write just the target word, wait until the auditory signal before beginning to write, and "try not to join your letters together because I find it tricky to read joined up writing." Children completed two practice trials before the experiment, which were repeated if necessary to ensure children understood the procedure.

Stimuli were presented across five pages (practice page, four experimental pages) to ensure that no words containing the same root were included on the same page, and in one of two pseudo-randomised orders, exactly as in Deacon and Dhooge (2010). During practice trials and after each experimental trial, the experimenter reinforced the procedural points as necessary. Most of these corrections were specific to capturing handwriting dynamics. For example, we reminded children to print their response. No information was provided to participants regarding spelling accuracy. The experimenter pressed [space bar] to commence the next trial after the child finished writing.

The spelling task generated two types of data: spellings and durations. Spellings were transcribed by two judges blind to experimental design. When judges disagreed, a third judge compared their transcription, the handwritten spelling and the target word to determine the final agreed-upon transcription. This was used to calculate spelling accuracy.

Writing duration data were scored and exported from Eye and Pen for the following interest periods: writing onset latency, root writing time. Writing onset latency is the time from the initiation of the auditory signal to the point at which the pen first touched the paper. Root writing time is the

Table 2. Descriptive statistics (*M, SD*) for Stimuli in Spelling Task, Including Univariate Analysis of Variance Statistics Comparing Word, Suffix, and Sentence Length and Frequency (SUBTLEX-UK Overall and CBBC), Base, Control, Inflected, and Derived Conditions

	Base M (SD)	Control M (SD)	Inflected M (SD)	Derived M (SD)	Univariate ANOVA, $F(2, 18)$
Word length (letters)	3.7 (0.8)	5.6 (1.3)	5.9 (1.5)	6.0 (0.6)	0.2, p = .8
Suffix length (letters)	0.0 (0.0)	1.9 (0.7)	2.1 (1.2)	2.3 (1.1)	0.3, p = .8
Sentence length (words)	8.3 (1.0)	8.6 (1.4)	7.9 (1.5)	8.0 (1.3)	0.2, p = .8
Log SUBTLEX-UK overall frequency	4.9 (0.4)	4.1 (1.0)	4.0 (0.6)	4.2 (0.5)	0.1, p = .9
Log SUBTLEX-UK CBBC frequency	4.9 (0.7)	4.2 (0.9)	4.2 (0.6)	4.3 (0.7)	0.0, p = 1.0

Note. SUBTLEX-UK Overall and CBBC: Van Heuven et al. (2014).

time from the pen first touching the paper until it lifts up to begin writing the first letter after the root, including all movements of the pen off and on the paper in between. Therefore, root writing time does not include any pauses at the end of the root morpheme. In the base condition, root writing time is equal to word writing time.

Results

Spelling data were analysed using linear mixed-effects (LME) modelling with maximum likelihood using the lme4 package (Bates, Maechler, Bolker, & Walker, 2014, Version 1.1–10) in RStudio (RStudio Team, 2016 Version 1.0.136). All models included random intercepts for participants and items. Within each factor, levels were ordered as shown in parentheses. The fixed effect of age group (younger, older) was a between-subjects variable. The fixed effect of condition (base, control, inflected, derived) was a within-subjects variable. Random slopes were included to keep models logically maximal according to the procedure outlined in Barr, Levy, Scheepers, and Tily (2013). Hence, random slopes were never included for interactions between within- and between-subjects variables. Random slopes were included by items for between-subjects fixed effects (i.e., age group) and by participants for within-subjects fixed effects (i.e., condition). Statistical significance was ascertained using likelihood ratio tests to compare full and null models. Significance of the interaction was tested by comparing the fully specified model to one with the additive main effects of age group and condition, without the interaction. Significance of main effects compared models with both main effects (but without the interaction) to the null model with only one main effect. If any of these fully specified or null model failed to converge, we removed random slopes from all models until convergence was achieved; this is indicated in text/table footnotes. Figure 1 illustrates the effect of condition and age group across the dependent variables (a) root accuracy, (b) writing onset latency, and (c) root writing time.

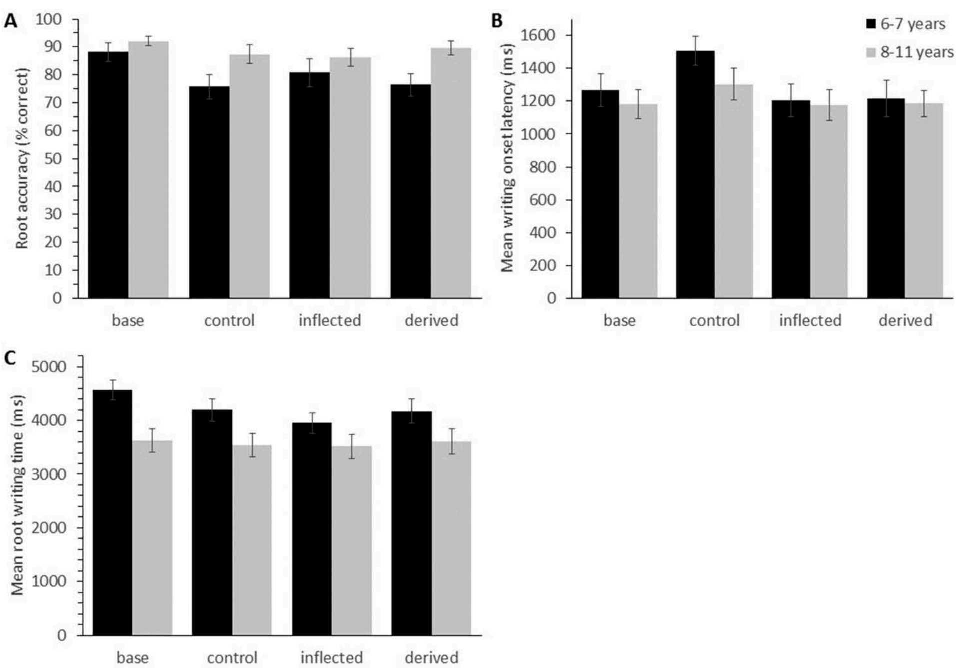

Figure 1. Mean (a) root accuracy (% correct), (b) writing onset latency, and (c) root writing time for base, control, inflected and derived words by younger and older children. *Note*. Error bars represent standard errors.

Accuracy

All 1,344 responses were analysed for root accuracy. Figure 1a illustrates the effect of age group and condition on percentage of responses that contained the correct root spelling. Because accuracy is binary data, we analysed this using binomial generalized linear mixed-effects models (GLME) with random intercepts by both participants and items.[1] We applied contrast coding with younger children's accuracy on base words as the baseline. Binomial GLME analyses predicting root accuracy (correct, incorrect) from the fixed factors condition (base, control, inflected, derived) and age group (younger, older) indicated a significant main effect of condition, χ^2 (3) = 15.23, p = .002, and age group, χ^2 (1) = 4.47, p = .034. The interaction was not significant, χ^2 (3) = 3.65, p = .30. Figure 1a clearly indicates that performance is close to ceiling across all conditions. Overall, 80.28% of younger children's and 88.86% of older children's spellings contained the correct root spelling. Analyses comparing root accuracy of control, inflected, and derived words indicated no significant differences between these conditions—control and inflected, χ^2 (1) = 0.56, p = .46; control and derived, χ^2 (1) = 0.38, p = .54; inflected and derived, χ^2 (1) = 0.01, p = .90. The main effect of condition is due to higher accuracy on base words than control, χ^2 (1) = 12.30, p < .001; inflected, χ^2 (1) = 8.10, p = .004; and derived words, χ^2 (1) = 8.41, p = .004. This effect is expected, as spelling demands are lower for shorter root words than longer comparison words.

Handwriting durations

Handwriting duration should be compared only where the letters being formed are identical, as some letters contain more strokes or movements than others (e.g., compare the movements necessary to produce *w* and *o*). Therefore, we limited our analyses to trials with correct root spellings, where the letters produced were matched; for instance, this would contrast the spelling of the *trick* letters in the words *trickle, tricked*, and *tricky*. A total of 186 of 1,139 of these responses could not be included due to missing data (spellings that were not completed by the child, or the recording failed) or because the participant initiated their response prior to the audio cue to commence writing (including within 100 ms of this cue). A further 18 trials were removed as outliers on the basis of writing onset latency and 49 due to word writing time (> 2 *SD* from the grand mean). Thus, analyses of handwriting durations were conducted on 886 of 1,139 trials. Table 3 contains summary statistics from each omnibus LME.

Morphological processing before spelling: writing onset latency

The LME analyses of writing onset latency were conducted to examine evidence of morphological processing before spelling. These analyses included fixed effects of condition (base, control, inflected,

Table 3. Linear Mixed-Effects Summary Statistics for Predicting Writing Onset Latency and Root Writing Time With Fixed Factors Condition (Base, Control, Inflected, Derived) and Age Group (6–7, 8–11 Years)

	Writing Onset Latency			Root Writing Time		
	β	SE	*t*	β	SE	*t*
(Intercept - base word spelling in younger children as baseline)	1274.77	101.50	12.56	4667.39	334.13	13.97
Condition: control	210.86	86.73	2.43	−407.96	122.69	−3.53
Condition: inflected	−95.73	83.14	−1.15	−449.78	126.67	−3.55
Condition: derived	−51.83	86.57	−0.60	−423.90	130.81	−3.24
Age group: older	−90.72	134.93	−0.67	−909.93	295.41	−3.08
Condition: control; Age group: older	−75.72	118.68	−0.64	261.12	168.65	1.55
Condition: inflected; Age group: older	102.94	113.83	0.90	351.52	173.48	2.03
Condition: derived; Age group: older	57.29	118.39	0.48	273.62	179.71	1.52

[1]Models predicting accuracy would not converge when including random slopes; therefore, these models do not include random slopes.

derived), age group (younger, older), and accuracy (correct, incorrect). Random slopes were included by participant for condition and by item for age group. Only the main effect of condition was significant, χ^2 (3) = 12.16, p = .007, with no other significant effects: interaction, χ^2 (3) = 2.28, p = .52; age group, χ^2 (1) = 0.82, p = .36.

Following on this main effect, a priori comparisons were conducted between control and each of the two-morpheme (inflected and derived) words. Writing onset latency on both inflected and derived words was significantly shorter than on control words, which did not differ from each other; control versus inflected, χ^2 (1) = 10.1, p = .001; control versus derived, χ^2 (1) = 8.29, p = .004; inflected versus derived, χ^2 (1) = 0.35, p = .55. Writing onset latency on base words was significantly shorter than control words but did not differ from inflected or derived: base versus control, χ^2 (1) = 6.33, p = .01; base versus inflected, χ^2 (1) = 0.29, p = .59; base versus derived, χ^2 (1) = 0.20, p = .65. This pattern shows that writing onset latency was similar for base word and two-morpheme words, despite two-morpheme words being longer. In contrast, writing onset latency was shorter for two-morpheme words than for the control words. Age group did not influence these effects (see Figure 1b).[2]

Morphological processing during spelling: root writing time

Root writing time could not be calculated for 24 out of 886 of the responses included in the analyses of handwriting durations because the participant went back and corrected the root part of the word after writing other parts of the word (e.g., adding letters later, crossing Ts, dotting Is) or the participant connected letters, making it impossible to tell where the root ended and another letter began. A further 38 items were removed as outliers (> 2 *SD*s from the grand mean), resulting in 824 of 886 items included in this analysis. Figure 1d illustrates the mean handwriting durations for root spellings, which are strikingly similar across conditions. LME analyses on the dependent variable root writing time, with the fixed factors condition (base, control, inflected, derived) and age group (younger, older), indicated a significant main effect of age group, χ^2 (1) = 6.20, p = .013; main effect of condition, χ^2 (3) = 10.75, p = .013; but no interaction, χ^2 (3) = 4.33, p = .23. Follow-up analysis compared the root writing time on each pair of conditions, revealing that root writing time for base words was significantly longer than control, χ^2 (1) = 11.24, p < .001; inflected words, χ^2 (1) = 13.75, p < .001; and derived words, χ^2 (1) = 10.05, p = .002. This is likely to reflect slowing that occurs toward the end of word writing. Root writing times did not differ between the conditions that were matched for word length; control, inflected, or derived words, χ^2 (1) = 0.26, p = .61; control versus derived, χ^2 (1) = 0.01, p = .93; and inflected versus derived, χ^2 (1) = 0.04, p = .84.

Summary statistics are provided in Table 3. Table 3 and Figure 1d illustrates that younger children are slower at spelling than older children and are particularly slow at spelling base words. Root writing time for both age groups is similar across control, inflected, and derived words.

Discussion

To evaluate whether morphological processing occurs before and/or during children's spelling, children 6–11 years of age completed a spelling-to-dictation task in which handwritten responses were digitised. We compared performance on two-morpheme (inflected and derived) words to single-morpheme words (base word and matched controls). Spelling accuracy was very high for both younger and older children. Analyses of handwriting durations revealed subtle differences between conditions. Across our two age groups (6–7, and 8–11 years), children had shorter writing onset latencies for two-morpheme words than single-morpheme words of the same length (controls). Further, the speed to begin these longer two-morpheme words was similar to that of much shorter

[2]Simple effects confirmed that there was no effect of age group in any condition; base, χ^2 (1) = 0.34, p = .56; control, χ^2 (1) = 1.96, p = .16; derived, χ^2 (1) = 0.00, p = .95; inflected, χ^2 (1) = 0.09, p = .76.

base forms. Morphological effects did not emerged on metrics of timing during the process of spelling itself; there were no differences in root writing duration across two-morpheme words (e.g., *rocking, rocky*) and controls (e.g., *rocket*). Interesting, though, the letters that comprised the root were written more slowly in base words (e.g., *rock*) compared to when written within any of the longer words. This, however, is likely due to slowing toward the end of the word. Crucially, there was no evidence of a difference across conditions matched for length.

Children began to spell two-morpheme words more rapidly than single-morpheme words of the same length (control words, e.g., *rocket*). This supports a role for morphology in input identification and central orthographic processes. Writing onset latencies for two-morpheme words (inflected and derived, e.g., *rocking, rocky*) were the same as for the base word (e.g., *rock*); this is striking given that the two-morpheme words were far longer. Together this is evidence that morphological processing occurs before spelling, facilitating writing onset latencies. In contrast to these effects prior to beginning to write, we did not find evidence of morphological processing on writing durations during the act of spelling. This is consistent with the idea that morphological processing primarily facilitates spelling by improving lexical access—either in input identification or during central orthographic processes. This may occur through the convergence of multiple phonological, orthographic, and semantic codes (Grainger & Ziegler, 2011; Harm & Seidenberg, 2004; Treiman, 2017) or greater lexical quality (Perfetti, 2007).

The consistency of our findings across younger and older spellers does not easily fit with "late" theories that propose that morphological processing does not occur until the alphabetic principle is secure (e.g., Ehri, 1995, 2005; Gentry, 1982). Evidence that children as young as 6 and 7 years seem to use morphological processing prior to spelling fits most neatly within statistical learning frameworks, which predict that both older and younger children show these effects (Deacon et al., 2008; Pacton & Deacon, 2008; Treiman, 2017; see Sawi & Rueckl, 2018, for a review of statistical learning in reading).

Our evidence of morphological processing prior to children's spelling builds on prior studies. In studies of copying with French speakers, morphological structure has been found to both slow (Kandel et al., 2008) and speed copying onset latencies for adults (Kandel et al., 2008; Quémart & Lambert, 2018), with no differences for 10- to 11-year-old children (Quémart & Lambert, 2018). The only previous study using dictation did not find evidence for morphological processing before spelling for adults (Quémart & Lambert, 2017). Most previous studies of handwriting durations have been with adults, and no previous studies have included participants as young as ours. The effects of morphological processing on speeding time to initiate spelling might be unique to our age range of participants. Further research could build on our findings to explore the impacts of the nature of the task, word features, language, and age of participants.

The absence of effects of morphological processing during spelling in the present study converges with the one prior study with similar-age children and conflicts with previous studies with older participants. As in our study, Quémart and Lambert (2018) did not show morphological effects on letter writing time or interletter latencies during copying for their 10-year-old participants. Prior studies with older participants (i.e., 12-year-olds and adults) have shown effects of morphological processing during copying (Kandel et al., 2008; Kandel et al., 2012; Quémart & Lambert, 2017, 2018). Even with more mature readers, these effects have emerged in differing metrics, in letter or stroke writing time before the boundary in some studies (Kandel et al., 2012; Quémart & Lambert, 2018) and inter-letter latencies at the morpheme boundary in some other studies (Kandel et al., 2008; Quémart & Lambert, 2017; cf. Quémart & Lambert, 2018). Our measure of root writing time included all of the letters in the root but not the interletter latency at the boundary with the next morpheme. Given this, nonsignificant effects of morphological structure during spelling are compelling. However, it remains possible that morphological processing has different effects at different stages of processing. The effect of morphological processing on speed of lexical access and the number of representations held in working memory may initially speed writing, but then the burden of peripheral orthographic processing of larger units might result in slowing. As a result, our null effects might have emerged because changes in speed at the finer level of analyses could not be detected; slowing and speeding might be levelled out over the course of writing the root or the whole word. For this reason, our results speak most clearly to the processes that occur prior to writing, rather than during writing. Future research should include fine-grained analyses that compare letter writing times and interletter latencies on identical letters before and after the morpheme boundary.

As we contrast our findings with those of prior studies, we keep returning to task differences as a likely cause of inconsistent findings. Most previous studies using handwriting durations were copying tasks. Copying involves reading as well as spelling processes. At a minimum, it seems likely that the cognitive demands of switching between reading and spelling processes may impact on patterns of handwriting durations and pauses. In dictation, reading is not required (or typically available). In copying, accurate responses could even be achieved by transcribing letter by letter, without lexical access. Spelling to dictation very likely draws on lexical access, at least to some extent. Another factor lies in the presence (or absence) of a sentence context. We included one, in keeping with standard spelling-to-dictation paradigms. In contrast, words were presented in isolation in Quémart and Lambert (2017). Sentence context likely helps to disambiguate meaning and grammatical status, increasing access to lexical information. Future research should examine whether the same patterns emerge when writing longer words or producing two-morpheme words in connected text; such contexts might lend themselves to unravelling potentially cascaded processes of handwriting production (e.g., Olive, 2014). Investigating effects of morphological processing while varying task demands (e.g., Quémart & Lambert, 2017) is a useful line of inquiry for this emerging field.

Turning to the accuracy data, we were surprised to find that children were just as accurate spelling the root of inflected and derived forms as in control words. This contrasts with a study with largely the same items and similar-age Canadian children (Deacon & Dhooge, 2010). The present participants might have been more able spellers, given their strong word reading abilities. Perhaps the words were not adequately challenging to reveal morphological processing in accuracy. This also highlights the value of examining handwriting durations; clear differences emerged in writing onset latency that were not clear in spelling accuracy. Participant and word-level characteristics are an important avenue for future study. The older age range was also quite broad; one might explore across this age range through to adulthood to connect the disparate literatures, linking this to handwriting speed as children develop.

There are several limitations that could be addressed in the future. Our use of words from a prior behavioural study ensured that our results could be integrated with prior studies. This also meant that stimuli did not permit some of the finer grained analyses of handwriting dynamics conducted in some of the previous studies. For example, we did not match the letter that occurred after morpheme boundaries and therefore could not examine durations at and after the morpheme boundary. Further, although the letter before the morpheme boundary was matched, this was sometimes written within a doublet (occurring before or across the morpheme boundaries). Previous research has shown that letter writing durations and interletter latencies are shorter for doublets than singlets (Kandel, Peereman, & Ghimenton, 2013). Although the present stimuli were perfectly matched for letters to the morpheme boundary, the phoneme–grapheme correspondences may differ slightly. For *win, wink, wins, winner* the pronunciation of the root final letter <n> differs in the control word (*wink*) compared to other conditions. We believe this will have had minimal impact on the data since this spelling is still easily decodable.[3] Moreover, LME models included random intercepts (and slopes) for items (and participants). This therefore allows for variable effects of individual items. Because pronunciation only varied for a small proportion of items, it is unlikely to have unduly influenced overall outcomes. Nevertheless, future research should ideally include items with both the same letters and sounds in all cases. Although controlling these letter properties, future research should examine whether fluctuations in fine-grained levels (such as stroke, letter, and pause durations; e.g., Kandel et al., 2012) remain significant across larger units such as morphemes. Future

[3]<n> is second most common spelling of the phoneme /ng/ (see Hanna, Hanna, Hodges, & Rudorf, 1966).

research should also consider a wider range of affixes and morphological features such as phonological transparency, productivity, and affix frequency.

In conclusion, we found significant evidence that children as young as 6 and 7 years of age engage in morphological processing as they prepare to spell in response to dictation. This supports theories that point to the role of morphemes in consolidation of lexical memory (Harm & Seidenberg, 2004; Nation, 2009; Perfetti, 2007) and statistical-learning theories of spelling development proposing that young children make use of multiple regularities in the orthography, including morphology (Deacon et al., 2008; Pacton & Deacon, 2008; Treiman, 2017). A great deal of further research is necessary to understand when and how morphological processing occurs during spelling production, and how these processes develop through childhood and into adulthood. In our view, analyses of handwriting durations will be a useful tool for investigating these and other questions as to the processes involved during spelling production.

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Appendix

Table A1 Stimuli for Morphological Spelling Task

Base	Target Condition	Stimulus and Sentence Frame Presented to Child
	Practice	Cats. The old lady has six cats. Cats.
	Practice	Snowy. In the winter the school yard is very snowy. Snowy.
Mill	Base	Mill. At the farm, we saw a mill. Mill.
	Control	Million. When she won the lottery, she got five million! Million.
	Inflected	Mills. The grain was turned into flour in the mills. Mills.
	Derived	Miller. The flour was poured into sacks by the miller. Miller.
Rob	Base	Rob. Paul knows that it is very naughty to rob. Rob.
	Control	Robin. The bird watcher spotted a robin. Robin.
	Inflected	Robbing. Yesterday, the man was caught robbing. Robbing.
	Derived	Robber. The police officer arrested the robber. Robber.
Rock	Base	Rock. While hiking, we climbed up a huge rock. Rock.
	Control	Rocket. After the blast-off, fire blazed behind the rocket. Rocket.
	Inflected	Rocking. In the wooden chair, Grandma was slowly rocking. Rocking.
	Derived	Rocky. The beach on the island was very rocky. Rocky.
Sing	Base	Sing. In the morning we like to sing. Sing.
	Control	Single. The ticket for the bus journey was a single. Single.
	Inflected	Singing. In the early morning the birds were singing. Singing.
	Derived	Singer. The punk band performed with a very famous singer. Singer.
Trick	Base	Trick. The magician did an amazing trick. Trick.
	Control	Trickle. I can see the rain starting to trickle. Trickle.
	Inflected	Tricked. Yesterday, I saw my brother getting tricked. Tricked.
	Derived	Tricky. The puzzle that Sarah completed was tricky. Tricky.
War	Base	War. The soldier left with his army to go to war. War.
	Control	Wart. The mean witch's nose had a big, shiny, green wart. Wart.
	Inflected	Wars. Remembrance Day honours those who fought in the world wars. Wars.
	Derived	Warrior. The chief of the tribe was a powerful, strong warrior. Warrior.
Win	Base	Win. When I play games, I like to win. Win.
	Control	Wink. During the parade, Santa Claus loved to wink. Wink.
	Inflected	Wins. The girl with the long legs always wins. Wins.
	Derived	Winner. The brown and white horse was the winner. Winner.